

DOE Laboratory Capabilities Upstream Oil & Gas Sensor Technologies

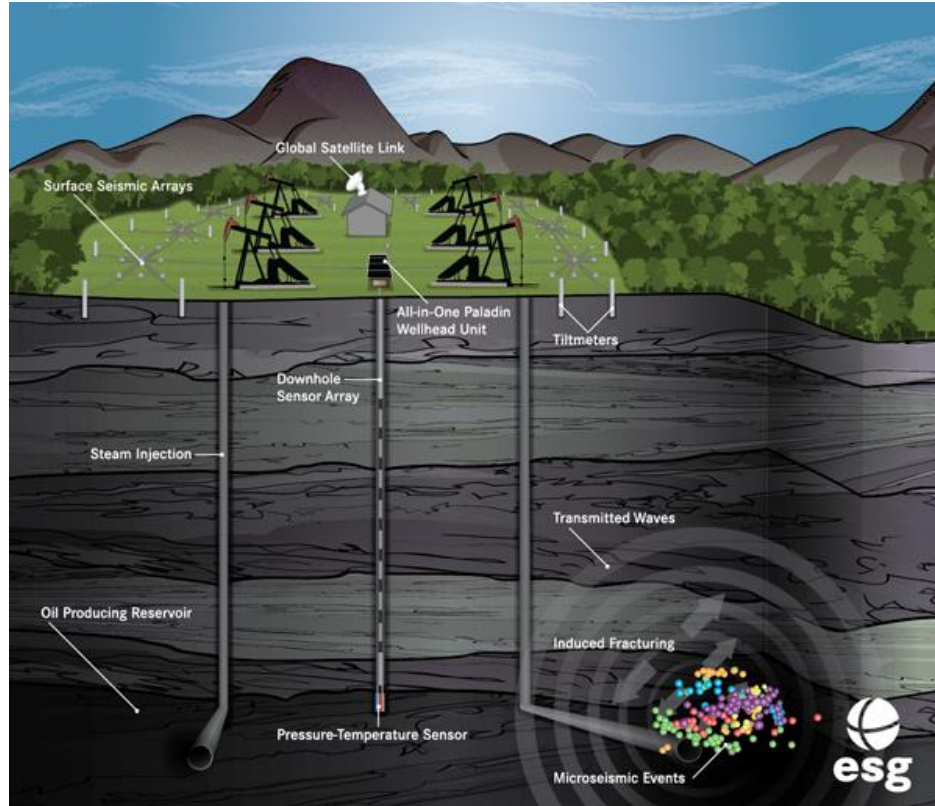
Presenter : Dr. Paul R. Ohodnicki, Jr.
National Energy Technology Laboratory

February 14, 2018
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Solutions for Today | Options for Tomorrow

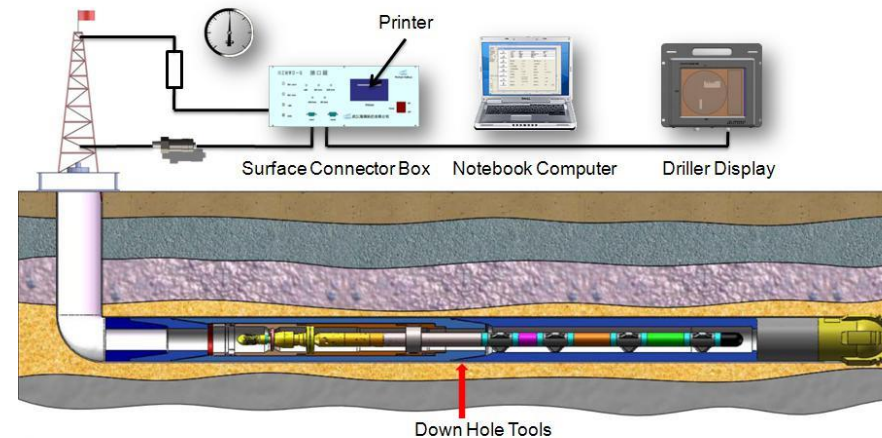
Upstream Oil & Gas Sensing and Measurement Needs



<https://www.esgsolutions.com/oil-and-gas/long-term-reservoir-monitoring>

Downhole Measurements

- Platforms: High Temperature Electronics (150°C+), Fiber Optics
- Physical Parameters: Temperature, Pressure, Flow, Strain, Seismic, Accelerometers, Inclination, Azimuth
- Others: Magnetic Field, Resistivity, Chemistry, Gamma Ray



Surface Measurements

- Emissions
- Seismicity
- Vented/Flared Gases
- Produced and Injected Water Monitoring

Upstream Oil & Gas Sensing and Measurement Needs are Broad and Diverse Spanning Emissions and Environmental Monitoring to Real-Time Process Monitoring and Control

DOE Laboratory Technologies and Techniques: Spanning From Full Field Validation to Basic Science



Technology Readiness Levels

Mature

Fiber Optic Distributed Temperature,
Acoustic, Strain Sensing (DTS, DAS, DSS)

6-7+

Acoustic Interrogation Methods

5-6+

Field Deployment,
Data Management,
and Data Analytics

Early

Fiber Optic Distributed Chemical
Sensing (DCS)

2-3

Coating and Fiber Development,
Packaging, Interrogation

Wireless Embedded Sensors in
Geological and Wellbore Environments

2-3

Telemetry and Sensor Device
Development

Nascent

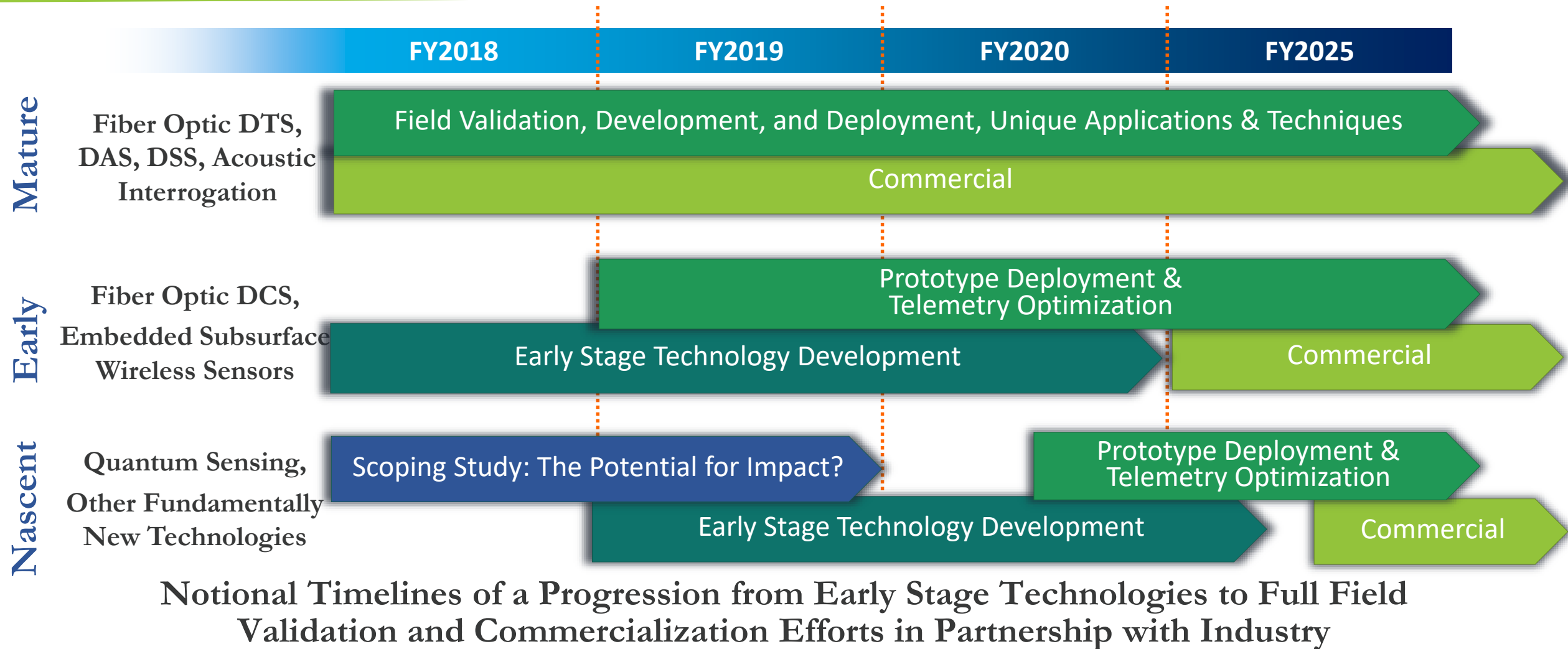
Quantum Sensing Techniques

1

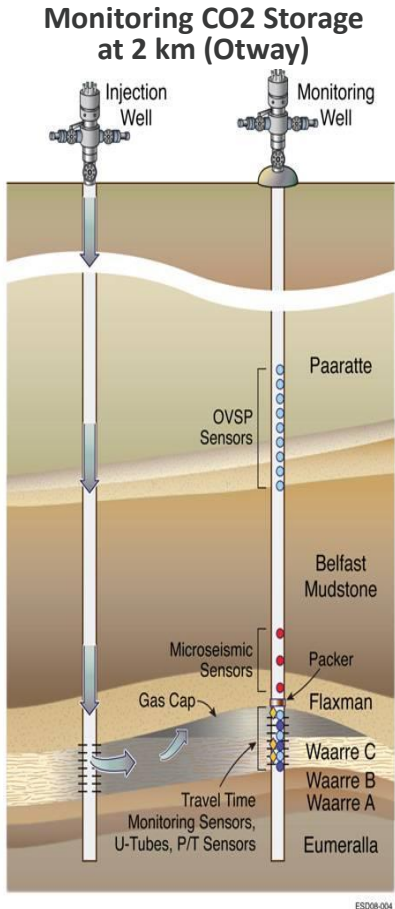
Scoping Study, Where Can it Make an Impact?

A Number of Advanced Technologies are Under Development By the National Labs, with
Emphasis on Providing Industry with New Technology Solutions Currently Unavailable

DOE Laboratory Technologies and Techniques: Maturation with an Ultimate Goal of Industry Impact

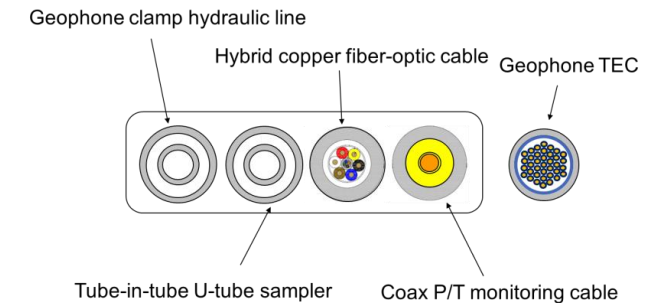
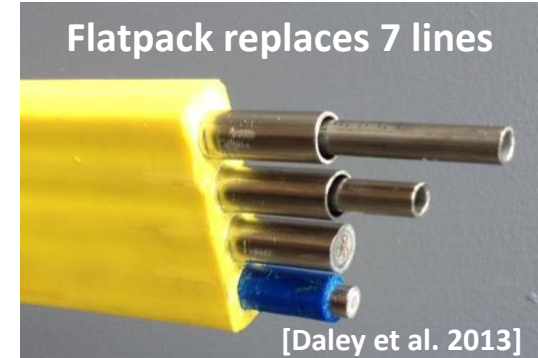


LBL A Leader in Field Testing with Fiber Optic Sensors: Deployment of DTS / DAS / DSS Techniques



Broad Experience Developing and Deploying Distributed Fiber-Optic Sensing Systems

- Integrated, robust suite of well-based and surface tools
- Configurable for application, deployment method, geologic environment
- Combine deployments from casing, tubing, wireline, behind casing
- Development and deployment of inexpensive fiber optic distributed temperature sensing (DTS), distributed acoustic sensing (DAS), and distributed strain sensing (DSS)
- Approaches for DAS data processing, analysis, and integration
- Experience with fit-for-purpose packages as well as leveraging existing telecom networks for sensing (e.g. “Dark Fiber”)
- Systems deployed at 15+ sites, surface to 3000 m+, -40 to 125 C
- Experience in O&G, GCS, geothermal, and environmental applications



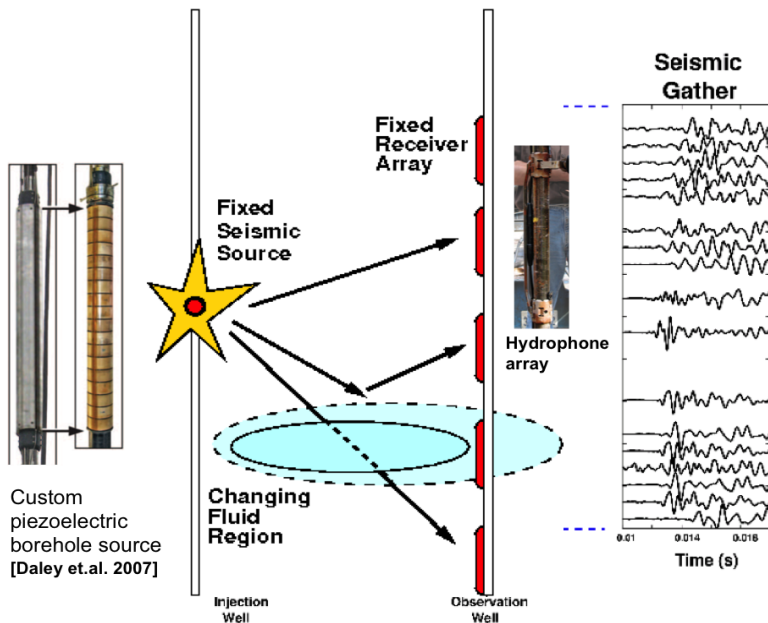
DAS + welded geophone pod

Lawrence Berkeley National Laboratory Has Decades of Experience in Sensor Development, Deployment and Field Testing Including Distributed Temperature and Acoustic Sensing

LBNL: Unique Geophysical Measurement Systems

Continuous Active Source Seismic Monitoring (CASSM)

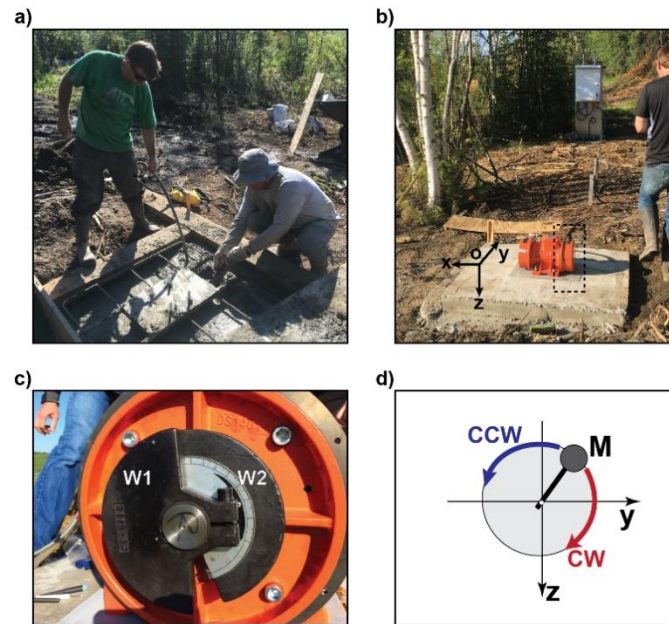
Concept: Semi-permanent downhole seismic sources/receiver systems for real-time imaging of flow & fracturing.



[Daley et al. 2007,2011, Ajo-Franklin 2011]

Automated Surface Seismic Sources: Surface Orbital Vibrator (SOV) Systems

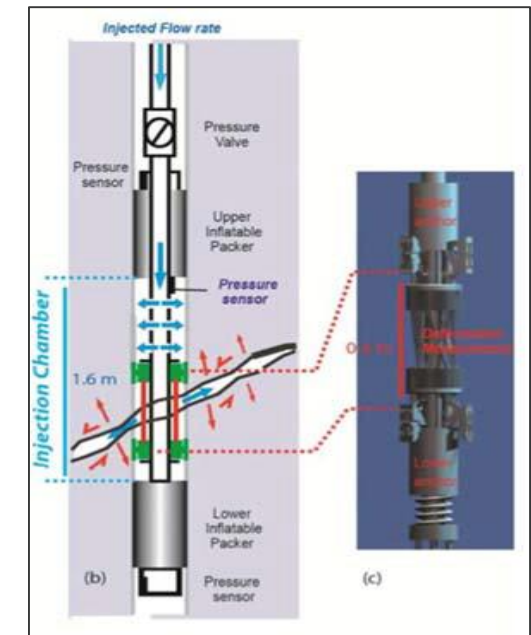
Concept: Automated surface sources coupled to DAS to enable reservoir and near-surface monitoring.



[Dou et al. 2017]

Fiber-Optic Strain Systems: SIMFIP Tool

Concept: Borehole fiber-optic system for precise strain measurements on stressed fractures and faults.

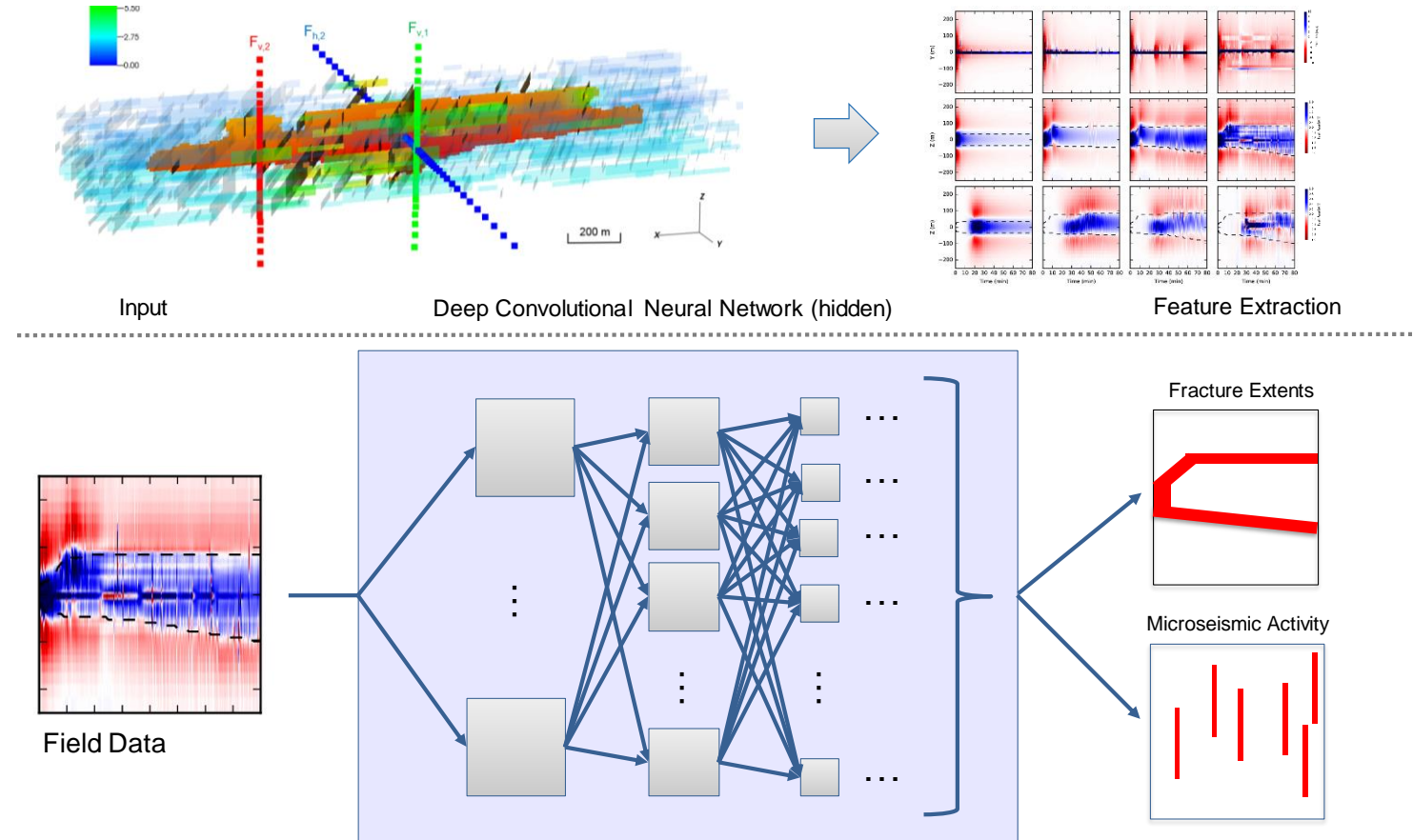


[Guglielmi et al., 2015]

LLNL Analytics Integration with DAS: Providing Operators with Actionable Information

- Simulate subsurface processes using the GEOS code and record synthetic DAS measurements
- Design and train a deep convolutional neural network (DCNN) to identify features
- Optimize DCNN and test on data

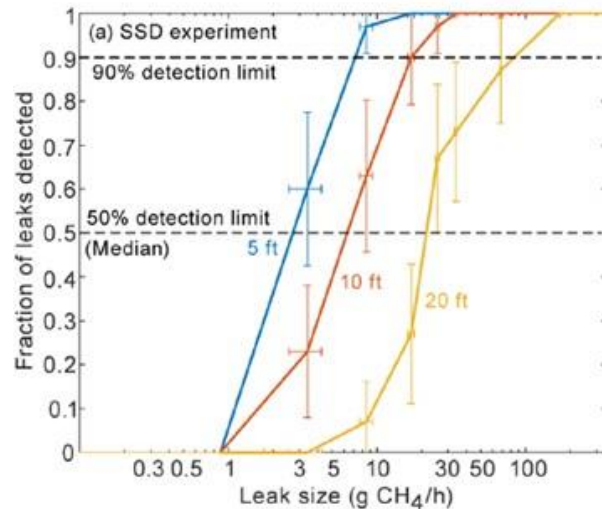
Capability could be used to make pumping schedule changes in real time during stimulation to target pay zone more effectively



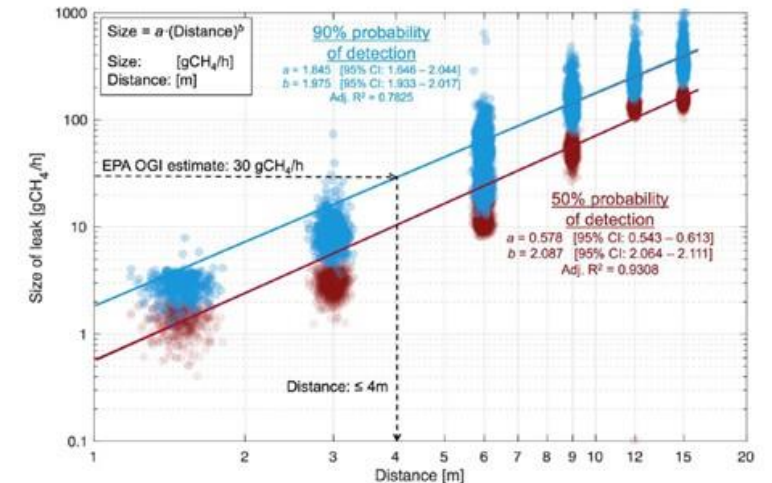
Lawrence Livermore National Laboratory Also Has Developed Capabilities for Real-time Analytics Methodologies for Analysis of Distributed Acoustic Sensing Data

SNL CHAMA Open Source Tools: Optimization of Emissions and Monitoring Networks

Field Validation



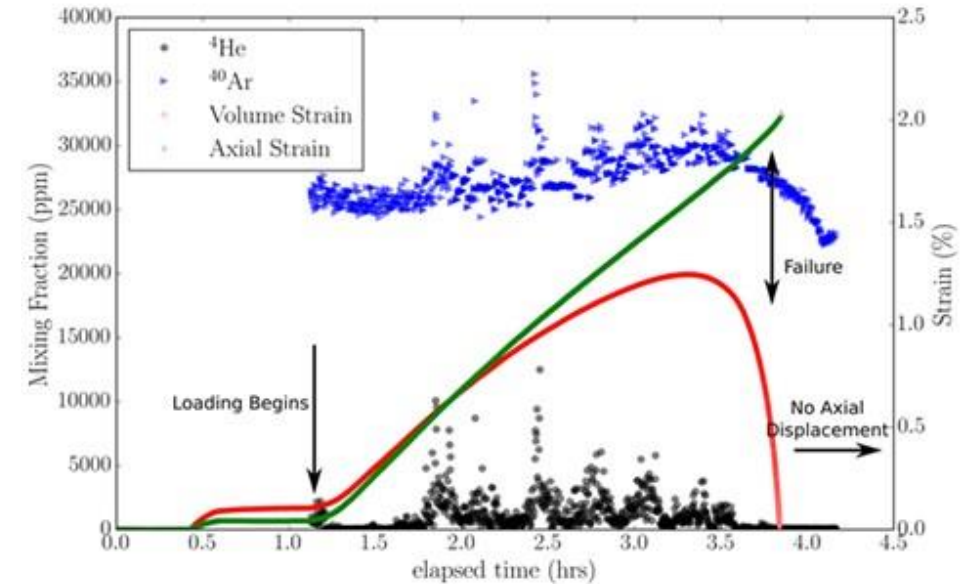
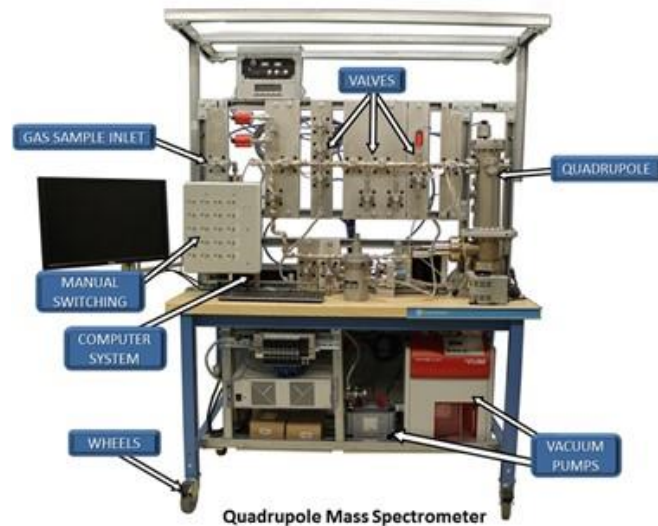
Chama is an open-source general purpose sensor placement optimization software tool currently able to quickly solve optimization problems with 1 million simulation data points and a 1000 feasible sensor locations on a desktop system.



Sandia National Laboratory has Established Sensor Placement and Optimization Tools to Better Understand Optimal Sensor Deployment for Leak and Emission Monitoring Applications

SNL Real-time Sensing and Analysis: Failure Detection in Natural and Engineered Materials

- Acoustic emissions (AE, energy emitted from microcracking expressed sonically) details locations of microstructural deformation
- Real-time trace-gas release/detection (doped or natural) as a precursor signal for deformation in natural and engineered materials

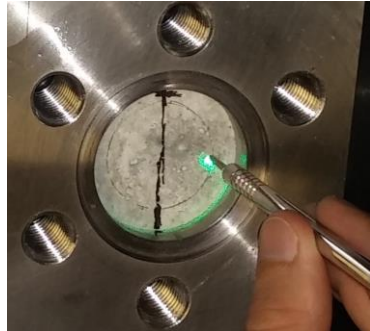


Bauer, S. J., W. P. Gardner, and H. Lee (2016), Release of radiogenic noble gases as a new signal of rock deformation, *Geophys. Res. Lett.*, 43, 10,688–10,694, doi:10.1002/2016GL070876.

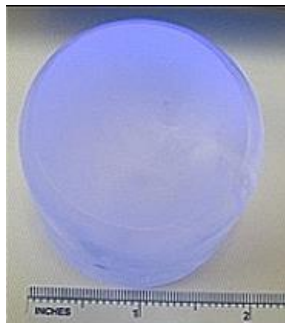
Sandia National Laboratory also has Demonstrated Capability for Real-time Sensing and Analysis of Failure Precursors Through Acoustic Emissions and Trace Gas Sensing Methods

ORNL Sensor Technology Examples: Upstream Oil & Gas Sensors, Industry Partnerships

Sensing Materials



ORNL “Smart” Cement – Stress can be Measured with Light



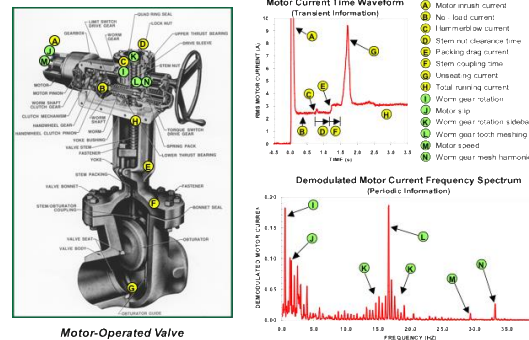
Gamma Ray Detectors

Two-inch diameter single crystal of $\text{SrI}_2(\text{Eu})$ grown at ORNL

Surface Applications

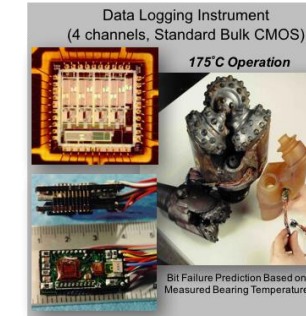


Custom Developed Charge Measurement System for Oil and Water Collection Tanks



“Virtual Sensing” of Flow Valve Behavior

Downhole Measurements



Bit Performance Sensor and Data Logger



Downhole Neutron Sources
(DD and DT Generators)

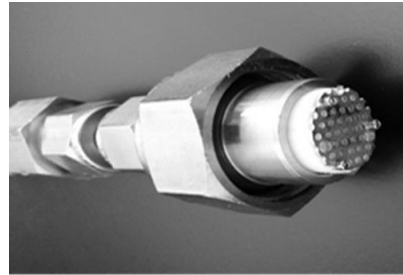
Oak Ridge National Laboratory Has a Broad Range of Other Sensing and Measurement Technology Programs and Prior Development Efforts to Leverage for Upstream Oil & Gas

NETL Sensor Technology Suite: Electromagnetics, Photonics, Electrochemistry, Advanced Manufacturing

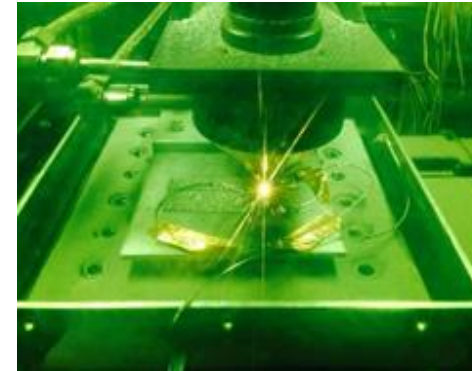
Distributed Optical Fiber
Sensors (Including Chemical)



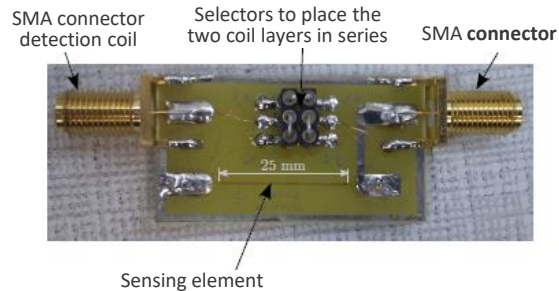
Advanced
Electrochemical Sensors



Advanced Manufacturing for Sensor Embedding



High Temperature Magnetometers
(Including Wireless)



Spectroscopy Techniques



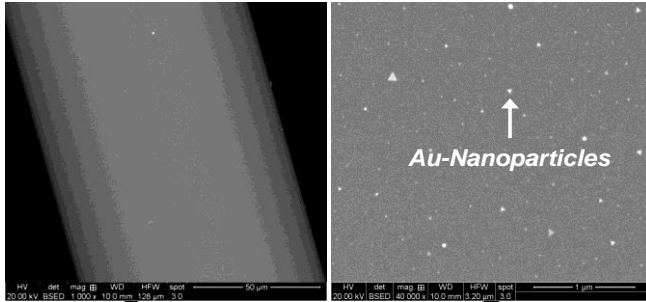
Sensor Infused Components



NETL Focuses on a Suite of Sensor Platforms with Complementary Cost, Performance, Information Content, and Geospatial Characteristics Coupled with Embedding Techniques

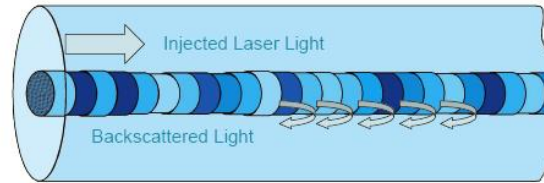
NETL Distributed Fiber Optic Sensor Technologies: Chemical Sensing (DCS) and Extreme Environments

Functional Sensor Coatings

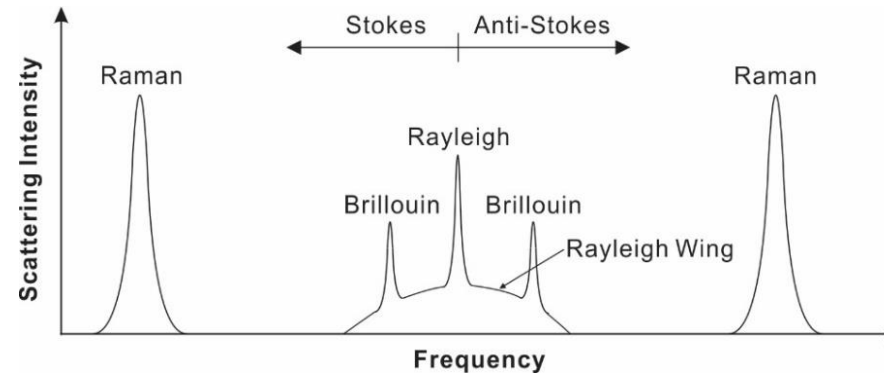


Novel Interrogation Techniques Leveraging Scattering and Interferometry

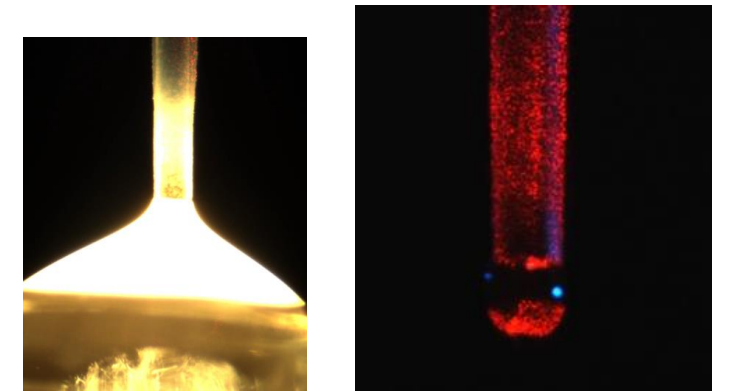
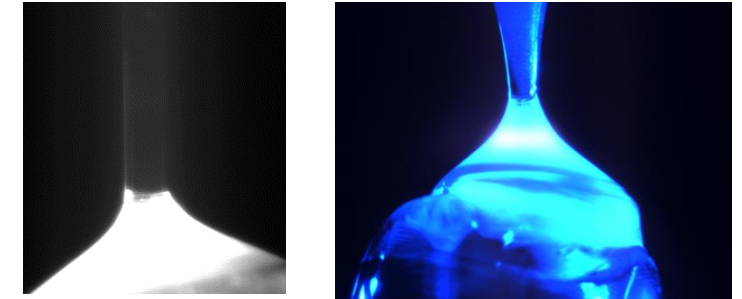
Imperfections in fiber lead to Rayleigh backscatter:



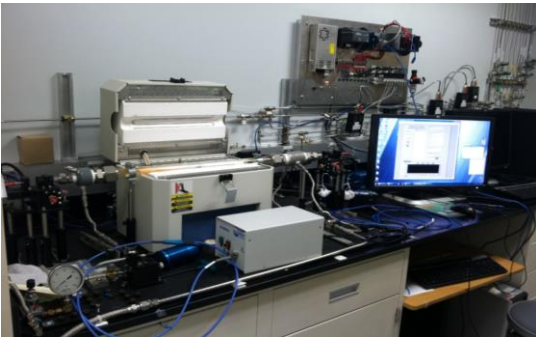
Rayleigh backscatter forms a permanent spatial "fingerprint" along the length of the fiber.



Laser Fabrication of Optical Fibers and In-Line Processing



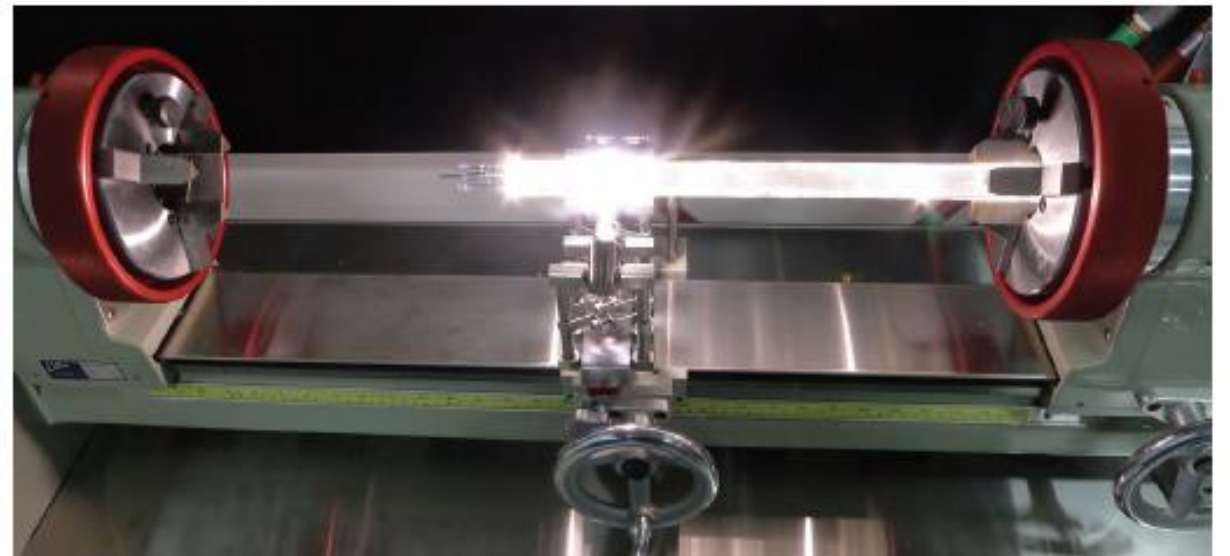
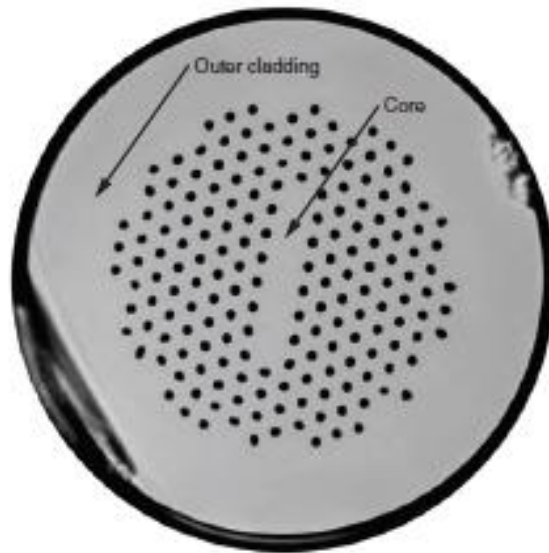
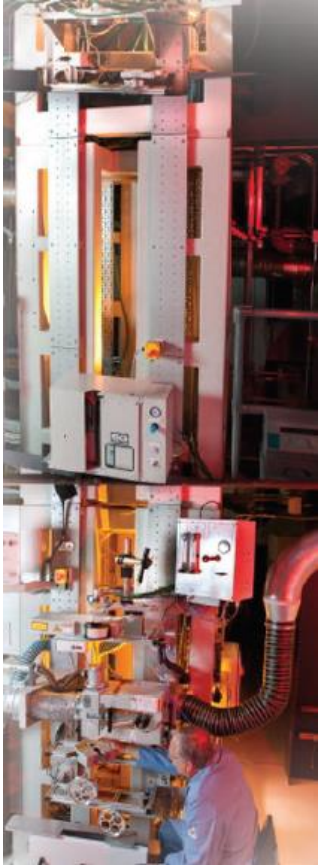
Automated Sensor Testing Reactors



NETL Research & Innovation Center Has Broad Capabilities Focused on Distributed Optical Fiber Sensor Technology with Emphasis on Extreme Temperatures and Chemical Sensing

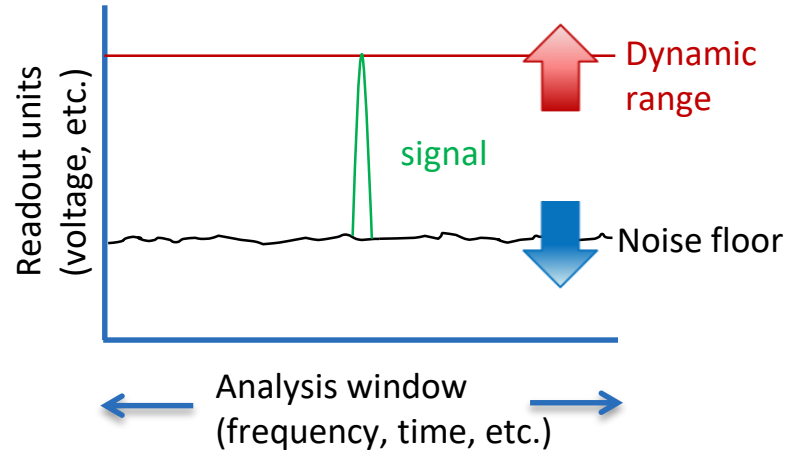
LLNL Engineered Optical Fibers: Optical Fiber Drawing and Manufacturing

Photonic Crystal and Other Advanced Fiber Manufacturing Technologies



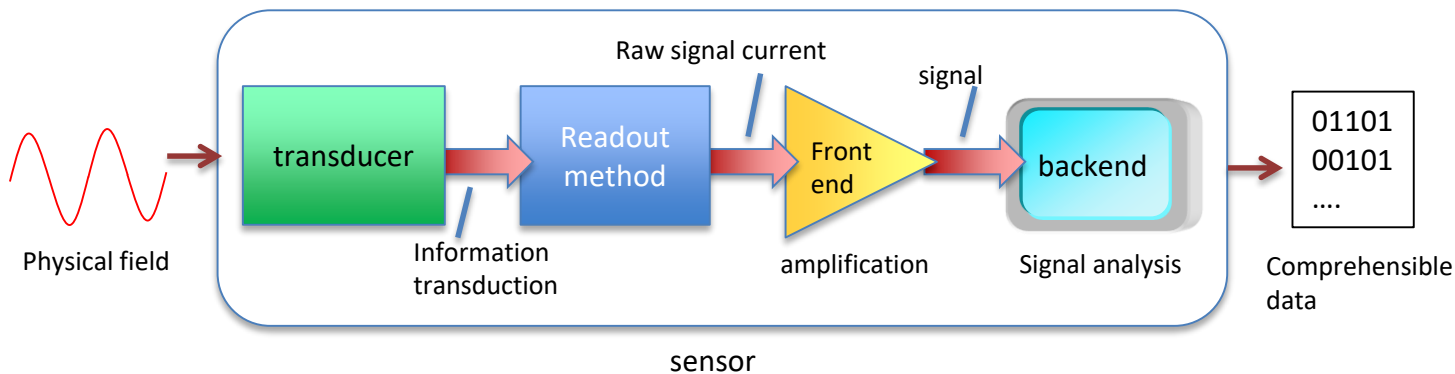
Lawrence Livermore National Laboratory Has Established Capabilities in Custom Optical Fiber Design, Modeling, and Fabrication that Can Be Leveraged in Sensor Technology Development

ORNL Quantum Sensing and Information Science: Beyond the Classical Limits



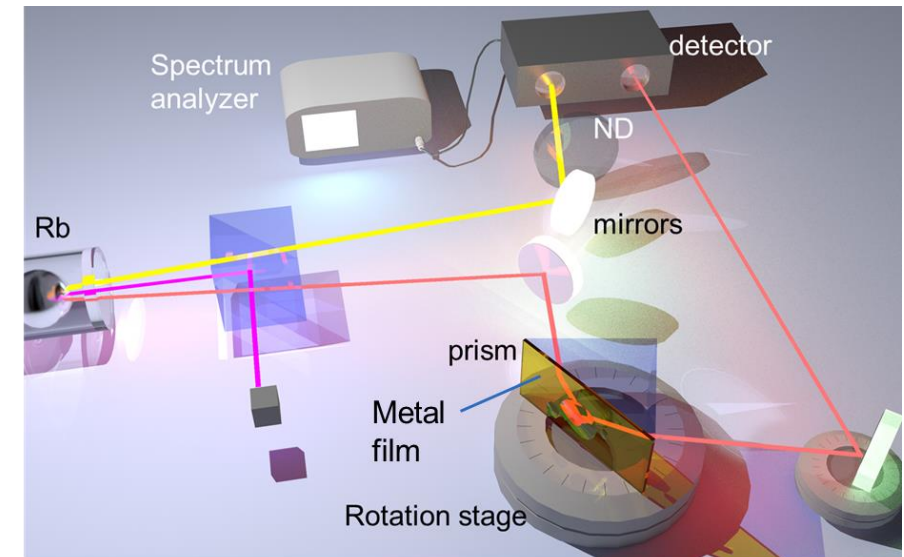
Applications

- Magnetometers
- Chem/bio detectors
- MEMS cantilever displacement



10 X increase of signal to noise (SNR) by decreasing the noise floor using **quantum noise reduction (QNR)** and **entanglement**, and increasing dynamic range using quantum signal modulation

Pooser, R. C. and Lawrie, B. J. "Plasmonic Trace Sensing below the Photon Shot Noise Limit," *ACS Photonics*, **3**, 8 (2016).



Oak Ridge National Laboratory Has Established World-Class Capabilities in Quantum Sensing and Quantum Information to Improve Performance of Traditional Sensor Technologies

US DOE National Laboratory System

Office of Science Laboratories

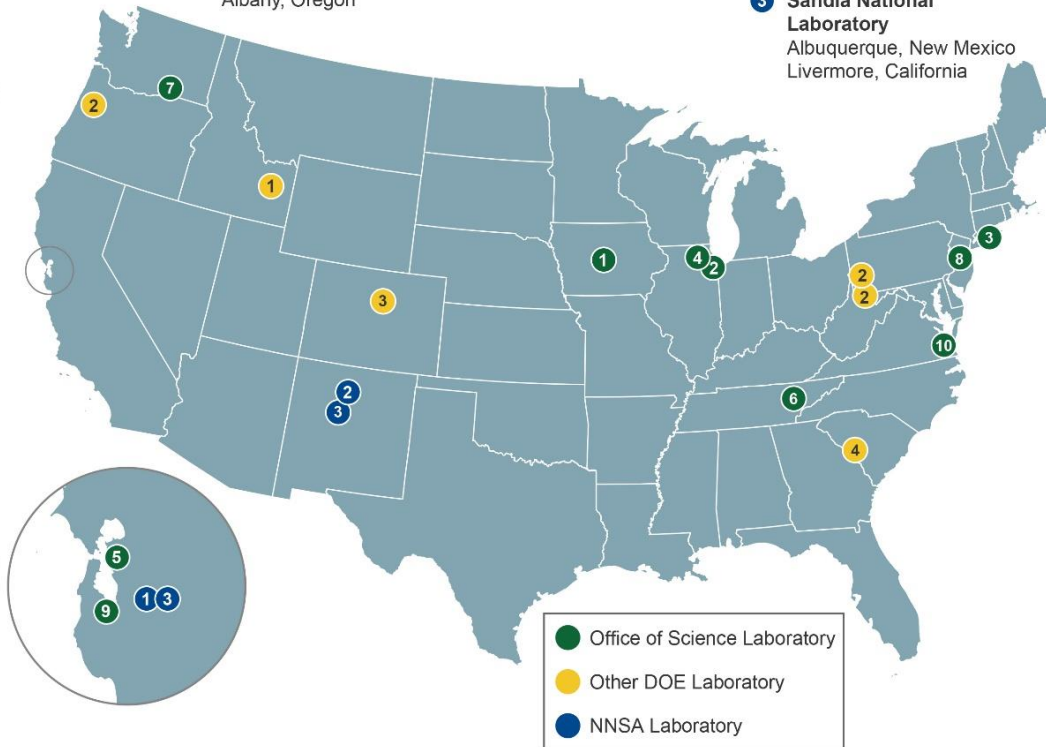
- 1 Ames Laboratory
Ames, Iowa
- 2 Argonne National Laboratory
Argonne, Illinois
- 3 Brookhaven National Laboratory
Upton, New York
- 4 Fermi National Accelerator Laboratory
Batavia, Illinois
- 5 Lawrence Berkeley National Laboratory
Berkeley, California
- 6 Oak Ridge National Laboratory
Oak Ridge, Tennessee
- 7 Pacific Northwest National Laboratory
Richland, Washington
- 8 Princeton Plasma Physics Laboratory
Princeton, New Jersey
- 9 SLAC National Accelerator Laboratory
Menlo Park, California
- 10 Thomas Jefferson National Accelerator Facility
Newport News, Virginia

Other DOE Laboratories

- 1 Idaho National Laboratory
Idaho Falls, Idaho
- 2 National Energy Technology Laboratory
Morgantown, West Virginia
Pittsburgh, Pennsylvania
Albany, Oregon
- 3 National Renewable Energy Laboratory
Golden, Colorado
- 4 Savannah River National Laboratory
Aiken, South Carolina

NNSA Laboratories

- 1 Lawrence Livermore National Laboratory
Livermore, California
- 2 Los Alamos National Laboratory
Los Alamos, New Mexico
- 3 Sandia National Laboratory
Albuquerque, New Mexico
Livermore, California



Upstream Oil & Gas Encompasses a Broad Range of Application Environments and Technical Requirements

A Broad Range of Capabilities in Advanced Sensing Technologies Exist Across the DOE National Labs

The Purpose of this Presentation is to Highlight a Just Few Key Relevant and Unique Capabilities within the DOE Lab System

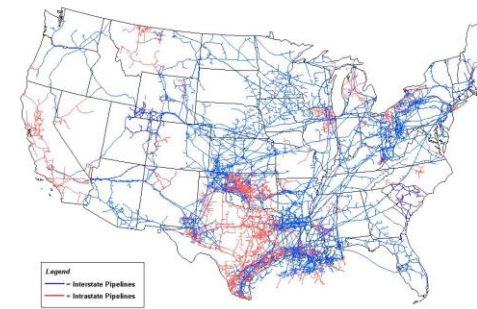
NETL: Embedded Sensing Fossil Energy Applications

Needs For Increased Visibility Span All Aspects of the US Energy Infrastructure

Power Generation



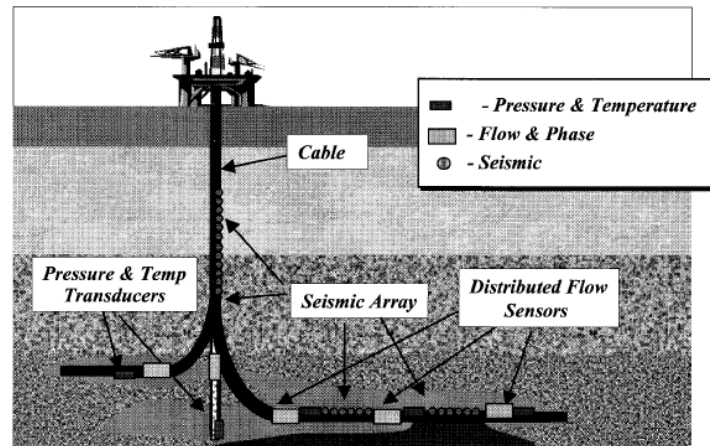
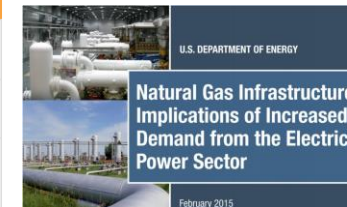
Natural Gas Infrastructure



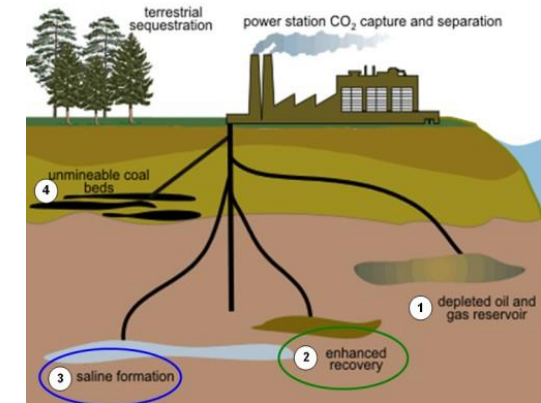
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Properties of Methane

Chemical Formula	CH ₄
Lifetime in Atmosphere	12 years
Global Warming Potential (100-year)	28-36



Unconventional / Offshore Oil & Gas



CO₂ Sequestration

Ubiquitous Embedded Sensors Combined with Geo-spatial Data Analytics is a Requirement to Achieve Desired Visibility Across the Fossil Energy Infrastructure: Current NETL Initiative

LBNL: The Geoscience Measurement Facility



- Only Lab in the complex with customized design-to-deployment geosciences instrumentation capability
- Designs, builds, tests, and operates world-unique tools for Earth, atmosphere, and ocean experiments
- Provides expertise and management support for mesoscale experiment and field projects

GMF At-A-Glance:

- 4 FTE Engineering and Technical Staff, plus scientific associates
- Over \$4M in equipment equity
- High Bay, Mobile Field Vehicles (4 wireline trucks), Machine Shop (CNC), Electronics Design, Large System Storage, Borehole Test Facilities (to 500 ft)
- **Supports Earth Science Across Range of Disciplines**

Development of Novel Experimental Approaches:

Geophysics: DAS, MEQ, InSAR, Coupled Fault flow/mechanics, active sources (CASSM)

Geochemistry: Deep well sampling, on-site analysis

Hydrology: Multi-level sampling, novel pressure/temperature measurements

Atmospheric sciences: Eddy flux, gas measurement, 4 season Arctic/Tropics stations



Fabrication



Wireline operations



Source Development

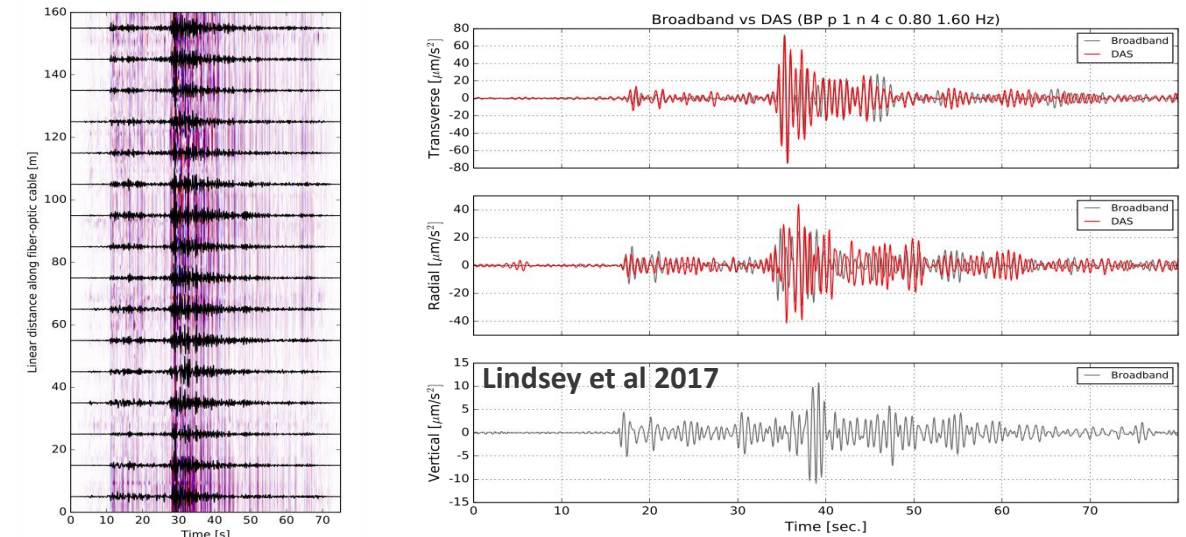
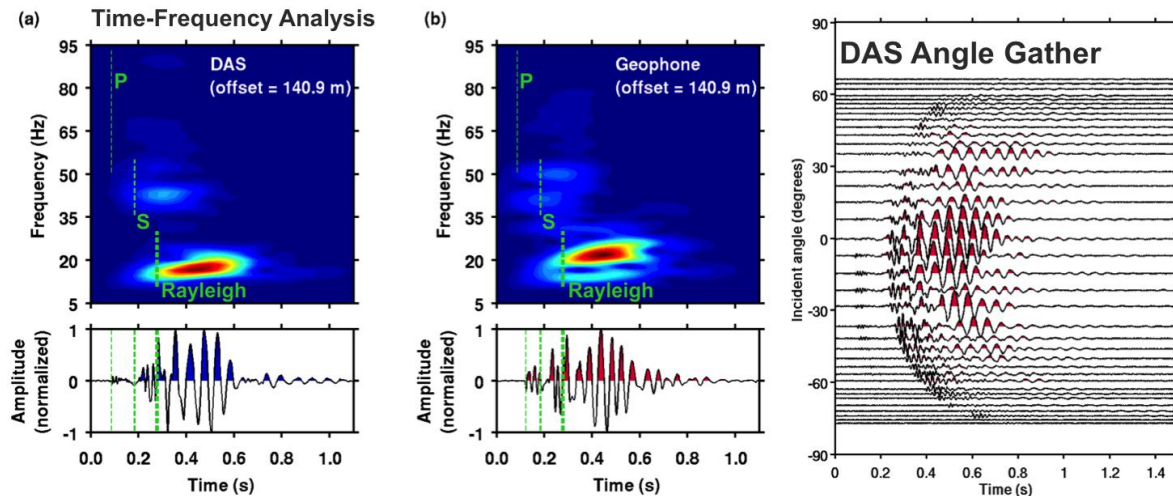
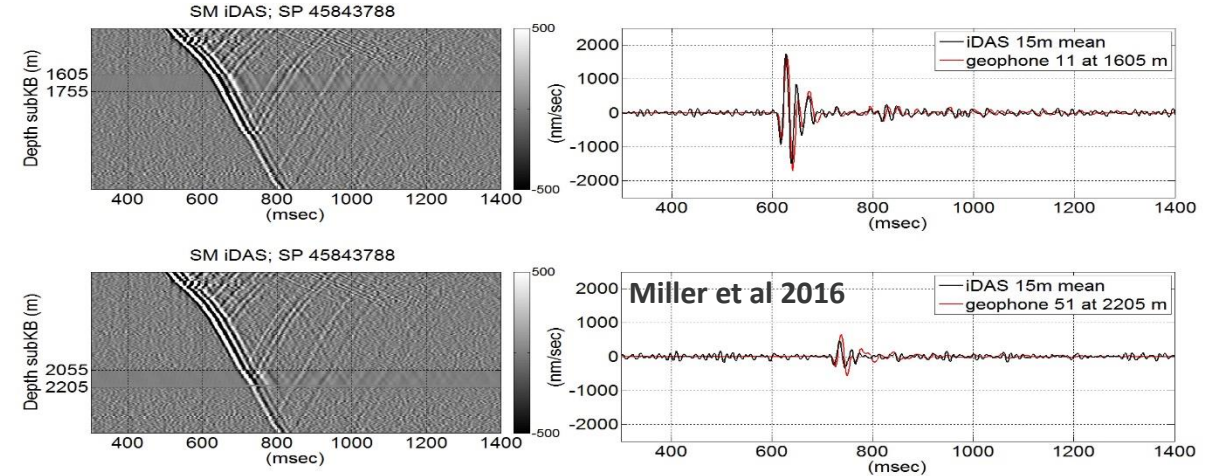


Tank Testing

LBNL: The Geoscience Measurement Facility



- Current DAS measurements noisier (10-15 dB) than classical inertial sensors but rapidly improving.
- Recent papers have demonstrated quantitative comparisons over the exploration band (5-100 Hz, Miller et al. 2016) and regional seismology (0.5-5 Hz, Lindsey et al. 2017) frequency bands to geophones/broadbands.
- Straight fiber shows strong directional sensitivity but new fiber geometries/packages show potential for improved response.



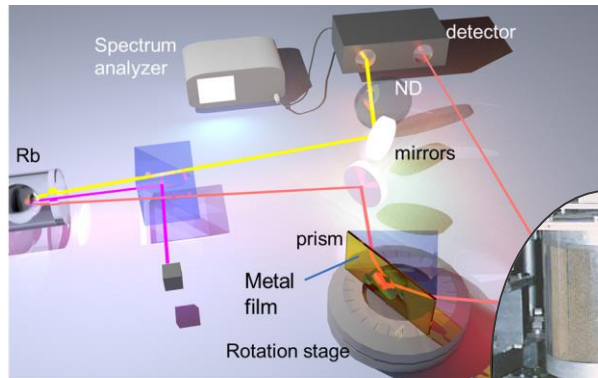
ORNL Sensors and Measurement Science: A Broad Suite of Capabilities and Efforts

We Research and Produce Highly Accurate and Precise Measurement Technologies for
Complex, Harsh, and High Data-volume Environments

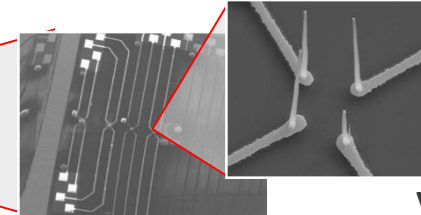
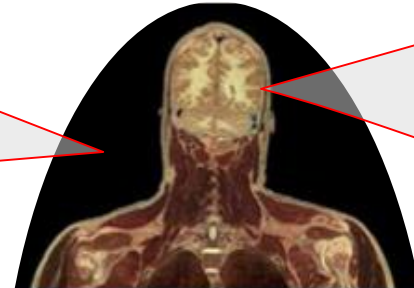


PHENIX detector subsystem:
300,000 readout channels, 40 μ s
refresh rate, timing resolution <25ps

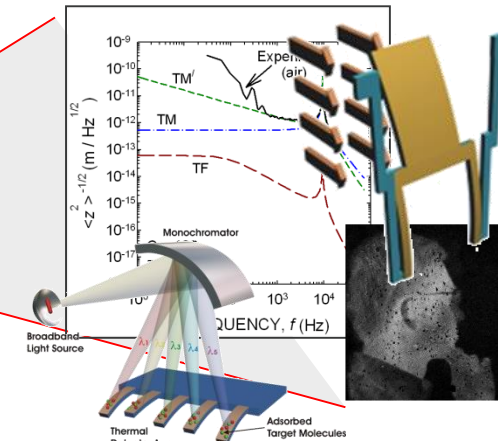
Quantum sensors
for trace detection
and distributed
sensing: **>10x**
enhancement in
SNR possible



Plasma temperature for Advanced
Toroidal Facility (ATF): **0.1-20MK**



VACNF arrays for measuring
neuro-electrical activity
(neuronal interface): can
resolve neurotransmitters at
sub-attomolar
concentrations



MEMS/NEMS devices to measure small displacements
(0.1pm/Hz^{-1/2}), **mass (10fg)**, and chemical concentration (ppt)

SNL / Advanced Manufacturing Lab (AML) Structural Health Monitoring Sensors and Self-Healing Materials



Biofouling & Marine coatings assessment



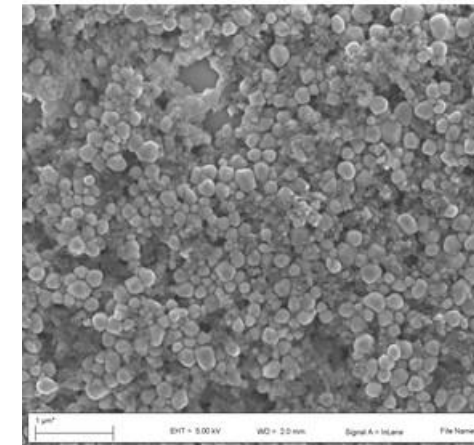
Structural Health Monitoring



MHK Environmental Effects on Composites



Nanomaterials Development



Biofouling Protection



Structural Protection



Composite Performance



Corrosion Protection



Biofouling Protection